

Pentaquarks and the X(3872) results from CDF

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for CDF Collaboration

Today:

- **Exotic spectroscopy: pentaquarks**
- **Exotic (?) spectroscopy: X(3872)**

CDF pentaquark search strategy

Exploit strong sides of the CDF experiment:

- great momentum resolution
 - can measure mass peaks down to $\sim 2\text{-}3$ MeV (e.g., $\Psi(2S)$)
- precision tracking:
 - able to reconstruct Ξ^- tracks in SVX!
 - good 3D vertexing: reduced backgrounds
- particle ID capabilities: identify protons, kaons
- not so good n , π^0 , γ reconstruction: avoid neutrals

$uudd\bar{s}$	Θ^+	$\rightarrow pK_s^0,$	$K_s^0 \rightarrow \pi^+\pi^-$
$ddss\bar{u}$	$\Xi_{3/2}^{--}$	$\rightarrow \Xi^-\pi^-,$	$\Xi^- \rightarrow \Lambda\pi^-, \Lambda \rightarrow p\pi^-$
$uuss\bar{d}$	$\Xi_{3/2}^0$	$\rightarrow \Xi^-\pi^+,$	$\Xi^- \rightarrow \Lambda\pi^-, \Lambda \rightarrow p\pi^-$
$uudd\bar{c}$	Θ_c^0	$\rightarrow D^{*-}p,$	$D^{*-} \rightarrow \bar{D}^0\pi^-, \bar{D}^0 \rightarrow K^-\pi^+$
$uudd\bar{c}$	Θ_c^0	$\rightarrow D^-p,$	$D^- \rightarrow K^-\pi^+\pi^+$
$uuud\bar{c}$	Θ_c^+	$\rightarrow \bar{D}^0p,$	$\bar{D}^0 \rightarrow K^-\pi^+$
$\bar{u}uudc$	Θ_c^+	$\rightarrow D^0p,$	$D^0 \rightarrow K^+\pi^-$

Datasets

At Fermilab: $p\bar{p}$ collisions, 1.96 TeV COM energy

Pentaquark production is not understood

- search in different kind of datasets

Use all Run II data: $\sim 250 \text{ pb}^{-1}$

→ Hadronic trigger data

- records events with at least 2 displaced tracks
- hard scattering events
- primarily contains $p\bar{p} \rightarrow c\bar{c}$ and $p\bar{p} \rightarrow b\bar{b}$

→ Jet20 data

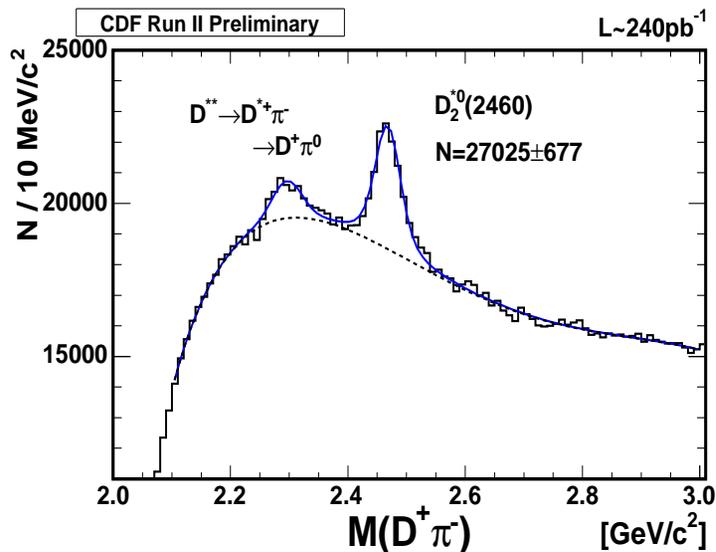
- each event has at least one jet with 20 GeV/ c , generic QCD
- trigger heavily prescaled

→ Min-bias and zero-bias data

- soft inelastic scattering

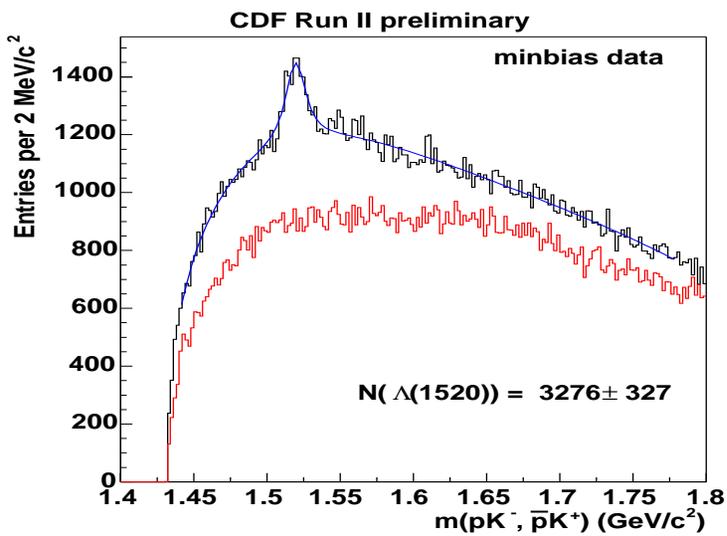
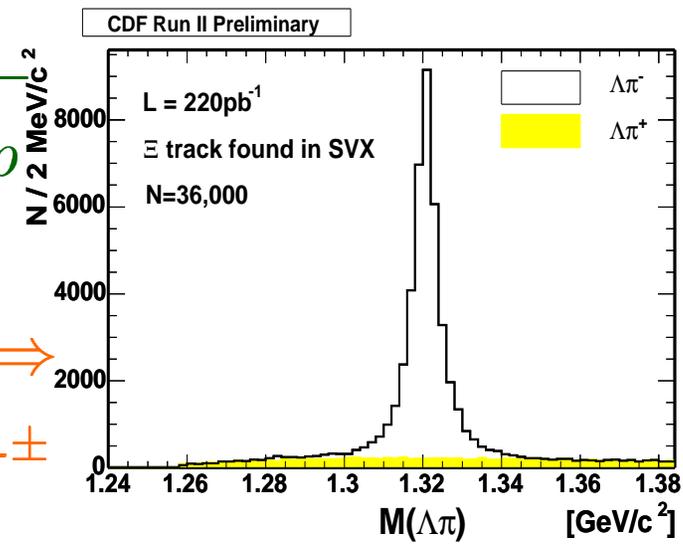
Reference signals

Well-established, similar to P_5 decays in our data:

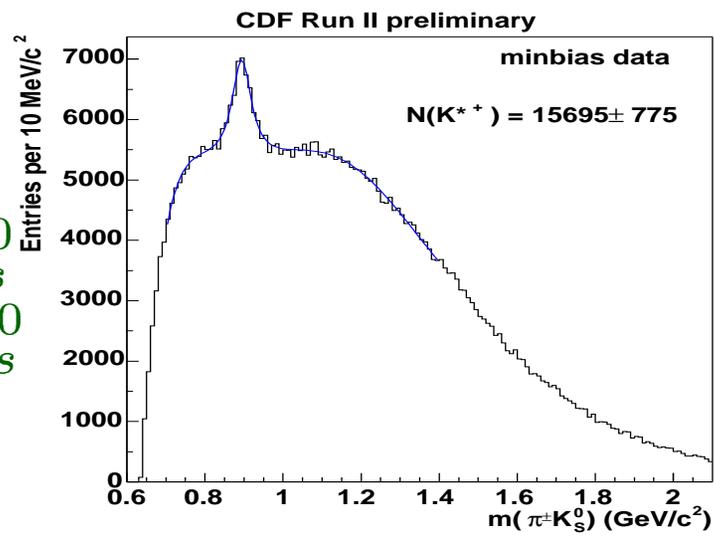


$\leftarrow D^{**} \rightarrow D^{*+} \pi^-$
 for $\Theta_c \rightarrow D^{*+} p$

$\Xi \rightarrow \Lambda \pi$
 for $\Xi_{3/2} \rightarrow \Xi^+ \pi^\pm$



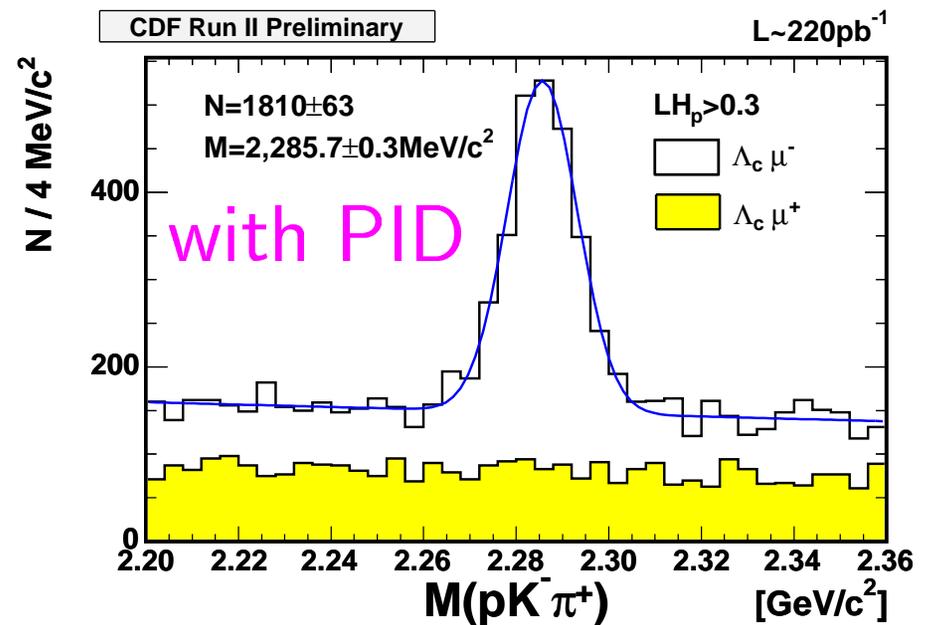
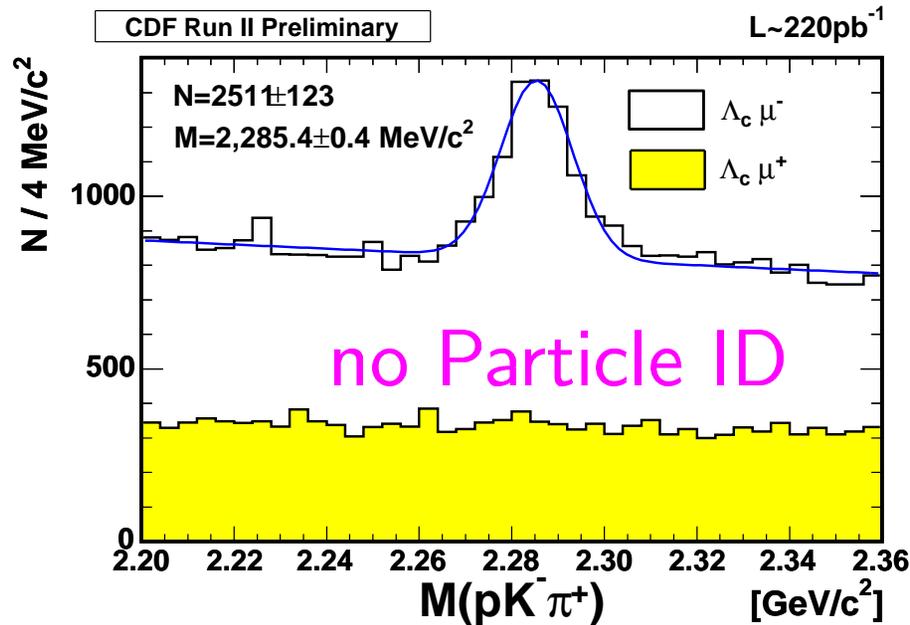
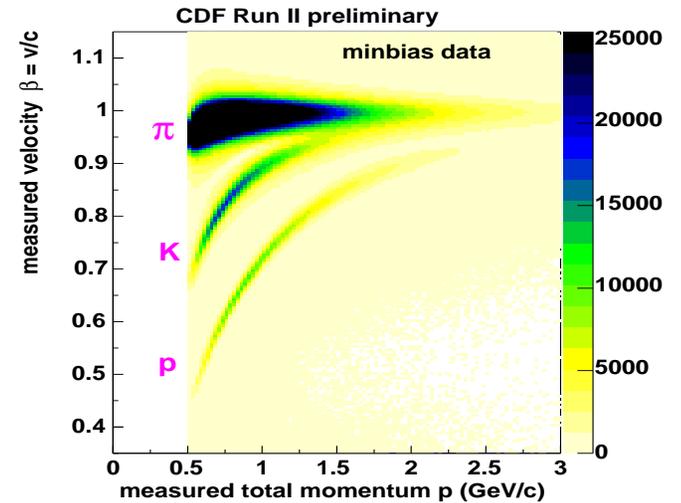
$\leftarrow \Lambda \rightarrow p K^-$
 $\Rightarrow K^{*+} \rightarrow \pi^+ K_s^0$
 for $\Theta^+ \rightarrow p K_s^0$



CDF particle ID

CDF has good PID system:

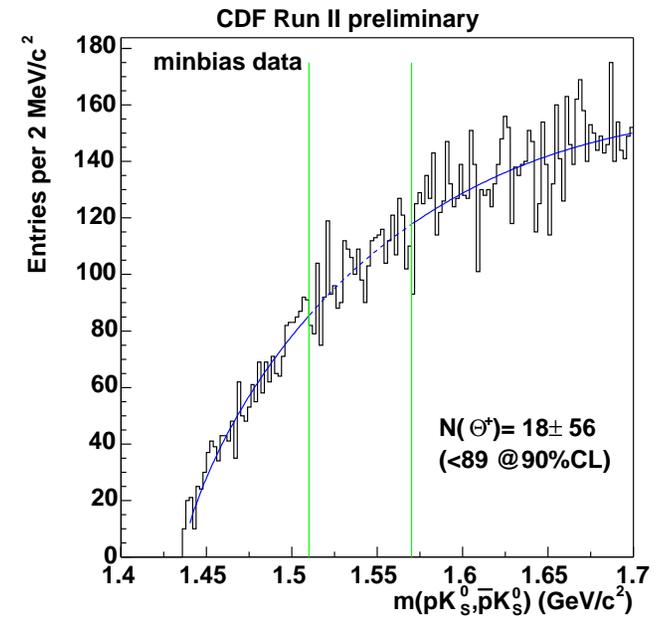
- use ToF and COT dE/dx
- identify protons
- strong background reduction



Search for Θ^+

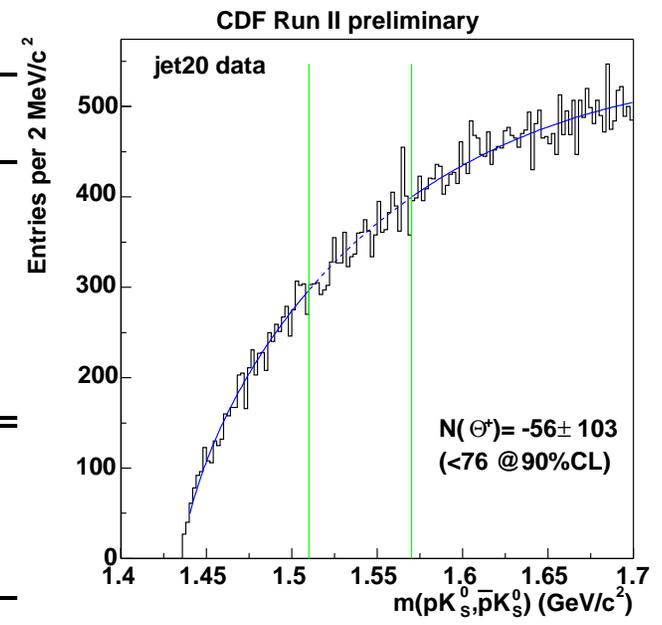
Reconstruct $\Theta^+ \rightarrow pK_s^0$

- use PID to identify protons
- Θ^+ yields relative to known resonances



No signal is found!

resonance	minbias data	jet20 data
$\phi \rightarrow K^+K^-$	19721 ± 273	26658 ± 385
$\Lambda \rightarrow pK^-$	3276 ± 327	4915 ± 702
$K^{*+} \rightarrow \pi^- K_s^0$	15695 ± 775	37769 ± 1390
$\Theta^+ \rightarrow pK_s^0$	18 ± 56	-56 ± 103
90% CL	<89	<76

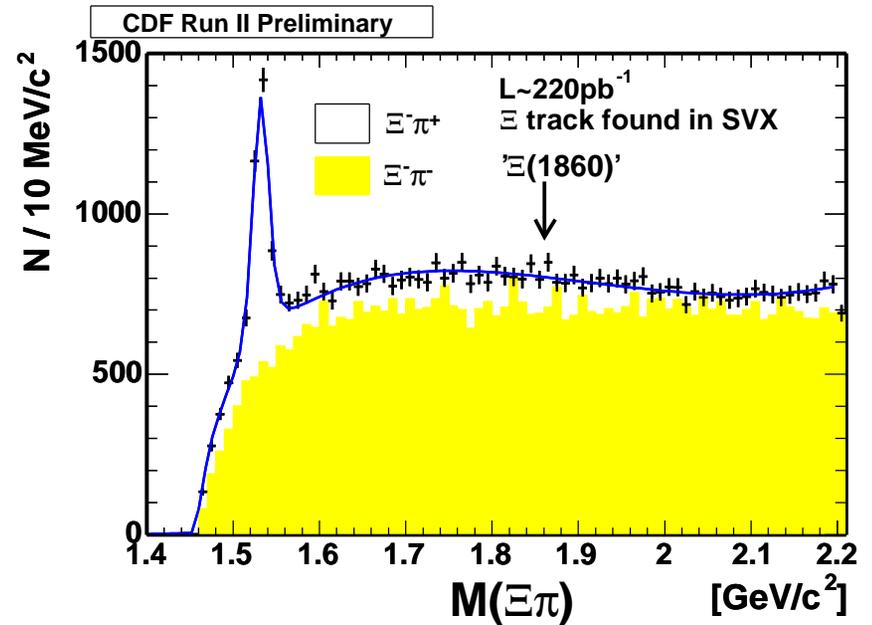


Search for $\Xi_{3/2}$

Reconstruct $\Xi_{3/2}^{0,-}$ $\rightarrow \Xi^- \pi^\pm$, $\Xi^- \rightarrow \Lambda \pi^-$

Special tracking for hyperons:

- $c\tau(\Xi^-) = 4.91$ cm
- leaves hits in SVX detector
- explicitly find Ξ^- tracks
- excellent background suppression
- better vertex and \vec{P} resolution



No signal is found!

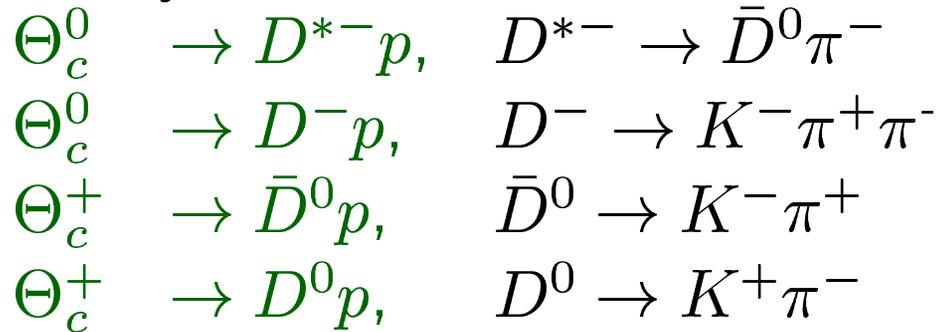
- clear, high statistics $\Xi(1530) \rightarrow \Xi^- \pi^+$
 - yields $\Xi_{3/2}/\Xi(1530) \lesssim 0.06$
- \Rightarrow if acceptance is equal (in progress)

channel	yield	
	fit	limit
$\Xi^- \pi^+$	57 ± 51	< 144
$\Xi^- \pi^-$	-54 ± 47	< 63

Search for Θ_c

Reconstruct several Θ_c modes:

- 3 decay channels:



- particle ID helps a lot
- consider prompt and long-lived Θ_c

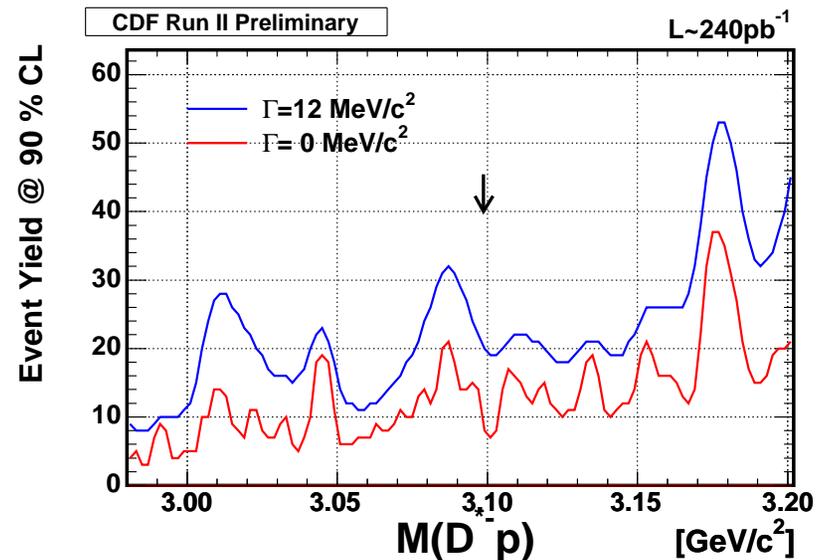
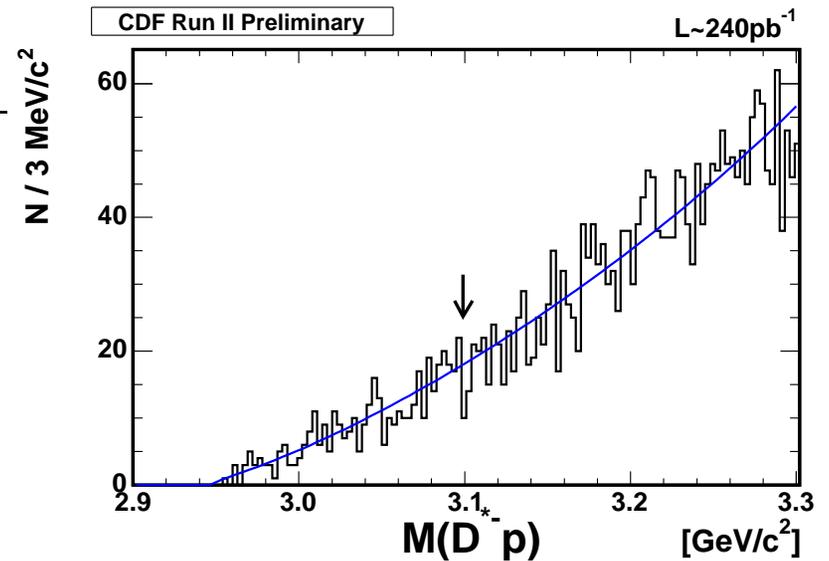
No signal is found!

- H1 mass estimate for $D^{*-} p$ mode:

$$m_{\Theta_c} = 3099 \pm 6 \text{ MeV}/c^2$$

⇒ calculate mass-dependent limits

On this page: plots for $\Theta_c^0 \rightarrow D^{*-} p$

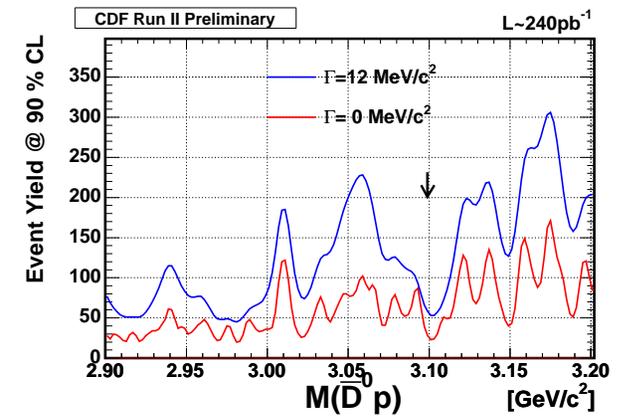
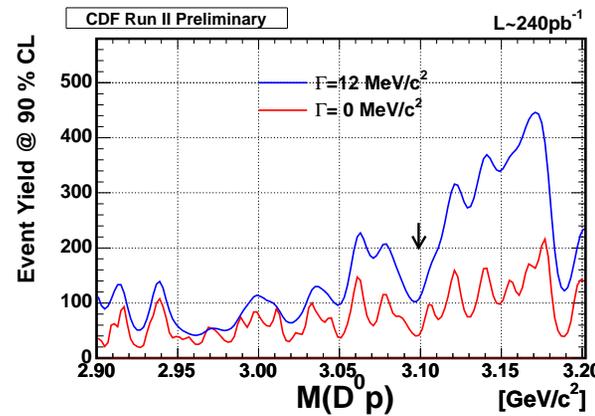
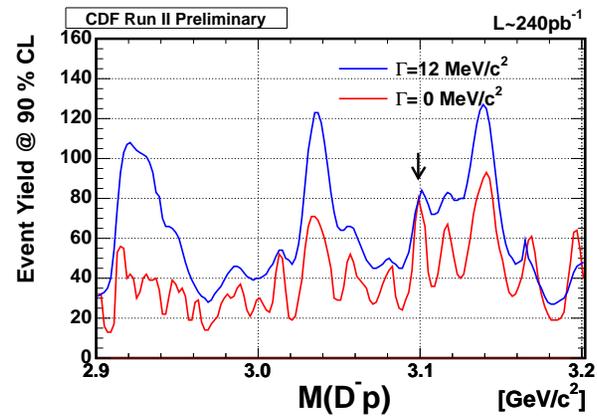
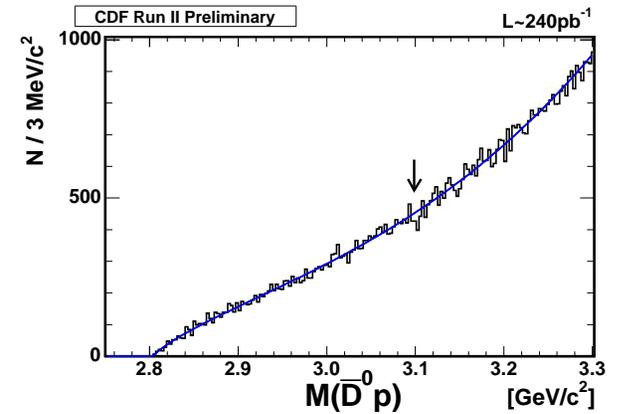
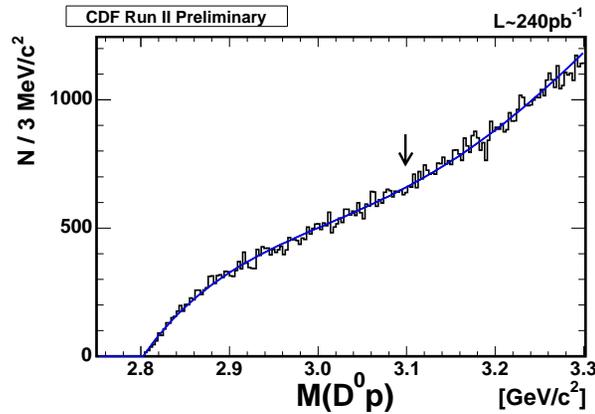
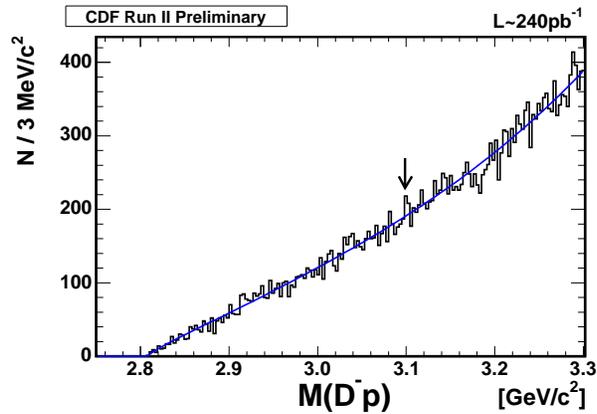


Results for other Θ_c channels

$$\Theta_c^0 \rightarrow D^- p$$

$$\Theta_c^+ \rightarrow D^0 p$$

$$\Theta_c^+ \rightarrow \bar{D}^0 p$$



No signal is found!

Limits for Θ_c

Limits calculation:

- search window: H1 mass $\pm 3\sigma$
- from 3082 to 3116 MeV/ c^2
- take the worst point from the limit vs mass plots

Reference channels		Search channels	
$N(D_2^{*0}) \rightarrow D^{*+}\pi^-$	6247 ± 1711	$\Theta_c \rightarrow D^{*+}p$	$< 21@90\%CL$
$N(D_1^0) \rightarrow D^{*+}\pi^-$	3724 ± 899	$\Theta_c \rightarrow D^-p$	$< 89@90\%CL$
$N(D_2^{*0}) \rightarrow D^+\pi^-$	34509 ± 1092	$\Theta_c \rightarrow \bar{D}^0p$	$< 87@90\%CL$
$N(D_2^{*+}) \rightarrow D^0\pi^-$	13628 ± 813	$\Theta_c \rightarrow D^0p$	$< 97@90\%CL$

Bottom line

CDF has found no evidence for pentaquark states Θ , $\Xi_{\frac{3}{2}}$ and Θ_c in several decay modes

Conclusions: production of exotic baryons in fragmentation may be severely suppressed with respect to normal baryon production

- exotic production mechanisms?

CDF continues studies of weak and strong decay signatures of exotic charmed and bottom baryons

- take advantage of large hadronic and J/ψ trigger samples at CDF

X(3872) observation at CDF

Belle announces in August 2003

$$B \rightarrow K J/\Psi \pi^+ \pi^-$$

CDF confirms within a month:

$$X(3872) \rightarrow J/\Psi \pi^+ \pi^-$$

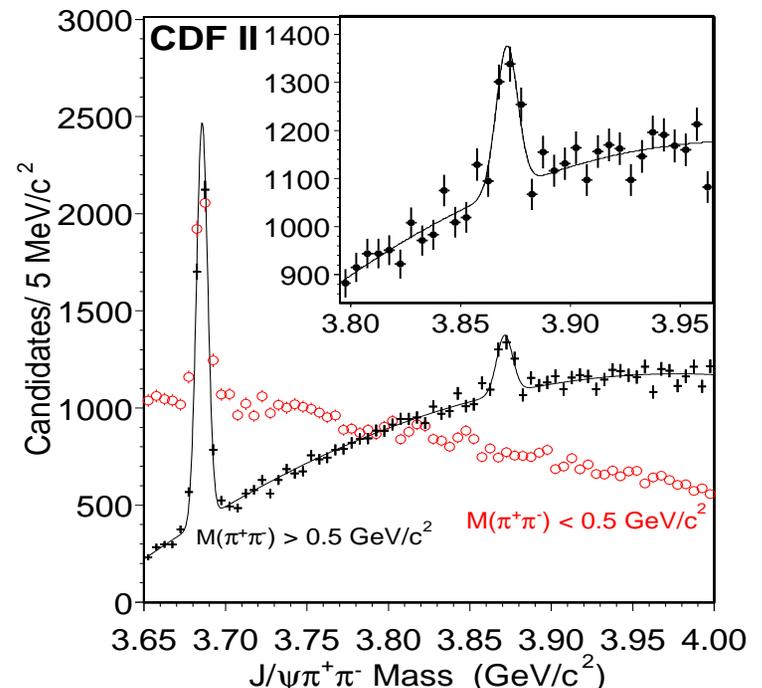
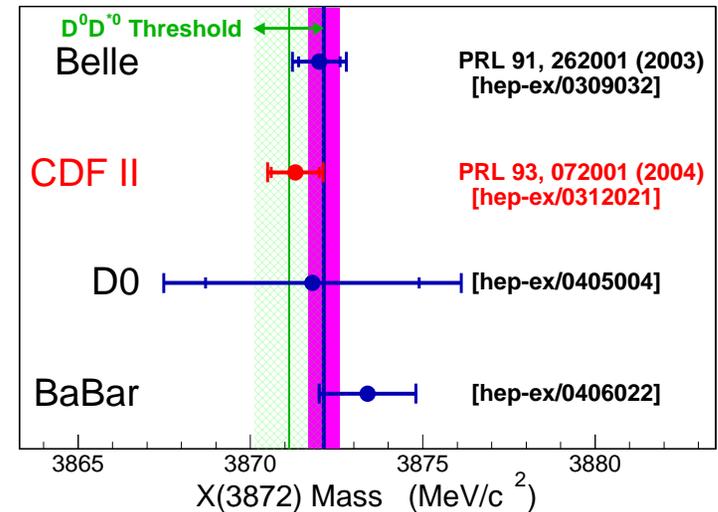
both at $> 10\sigma$ level

The mass:

- not easily explained as $^3D_2 c\bar{c}$
- CDF: $m_X = 3871.3 \pm 0.7 \pm 0.4 \text{ MeV}/c^2$

The width:

- compatible with zero
- CDF: $\sigma = 5.44 \pm 0.72 \text{ MeV}/c^2$
- Belle: $\Gamma = 1.4 \pm 0.7 \text{ MeV}/c^2$



The nature of X(3872)

Primary hypotheses:

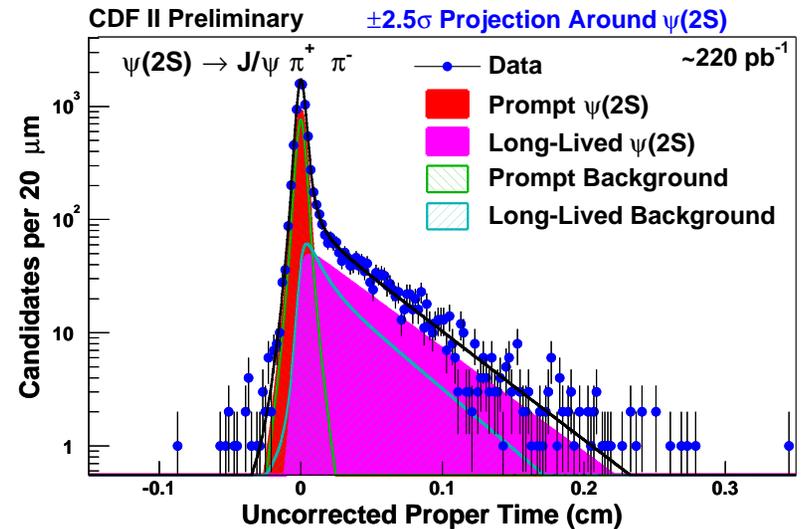
- a charmonium state?
 - 1^3D_2 most natural choice
 - others possible, hep-ex/0407033
 - problems in each case!
- a DD^* molecule? not clear

Measure properties:

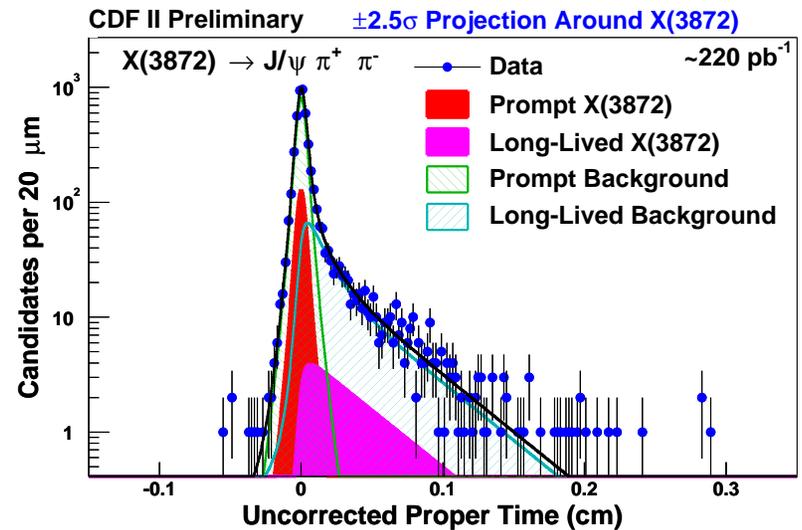
- quantum numbers, other decays
- “lifetime”, production, $m_{\pi\pi}$

At CDF:

- measure lifetimes
 - charmonium-like production
- study $m_{\pi\pi}$
 - signal enhancement for high $m_{\pi\pi}$
 - \Rightarrow possibly $X(3872) \rightarrow J/\Psi \rho$
 - $m_{\pi\pi}$ shape analysis in progress



$$f_{longlived}^{\psi(2S)} : 28.3 \pm 1.0 \pm 0.7\%$$



$$f_{longlived}^{X(3872)} : 16.1 \pm 4.9 \pm 2.0\%$$

Conclusions

- performed pentaquark searches in channels:

Θ^+	$\rightarrow pK_s^0$		
Θ_c^0	$\rightarrow D^{*-}p$	$\Xi_{3/2}^0$	$\rightarrow \Xi^- \pi^+$
Θ_c^0	$\rightarrow D^-p$	$\Xi_{3/2}^{--}$	$\rightarrow \Xi^- \pi^-$
Θ_c^+	$\rightarrow \bar{D}^0 p$		
Θ_c^+	$\rightarrow D^0 p$		

- CDF analyzed large data sample, with clear reference signals
 - no signal observed, yield limits are calculated
 - more modes will be added in the near future
- studied $X(3872) \rightarrow J/\Psi \pi^+ \pi^-$
 - 10σ peak, measured mass
 - charmonium-like: long-lived fraction similar to $\Psi(2S)$
 - properties are being investigated further

Backup slides

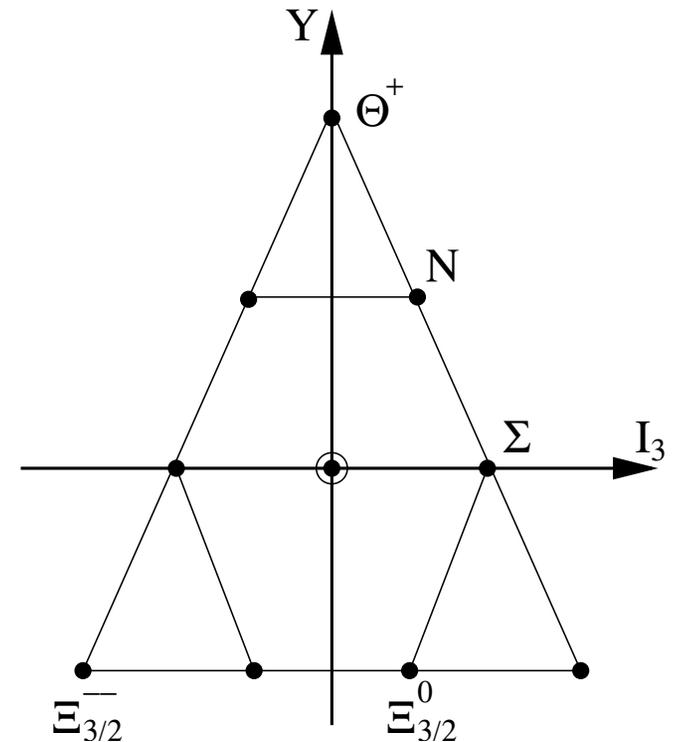
Introduction into theory

Exotic baryons:

- quantum numbers **can't be explained by qqq** configuration
- lowest lying $\bar{\mathbf{10}}$ of states containing u, s, d quarks was predicted by Diakonov, Petrov and Polyakov in 1997
- **strong decays, but narrow widths**

Bound states of 5 quarks:

- $q\bar{Q}q qq$ Karliner&Lipkin
- $(qq)^2\bar{Q}$ Jaffe&Wilczek
- P5 containing heavy quarks expected



Experimental field overview

History:

- searches since 1960s
- first clear observations: 2002
- currently: about 10-12 observations, 3 non-observations
- all states are narrow!

Summary of observed states:

state	decay	mass	observed by	not confirmed
$uudd\bar{s}: \Theta^+$	$\rightarrow nK^+$	~ 1540	LEPS, CLAS, etc	BES, PHENIX
$uudd\bar{s}: \Theta^+$	$\rightarrow pK_s^0$	~ 1530	DIANA, ZEUS, etc	BES, HERAB
$uudd\bar{c}: \Theta_c^0$	$\rightarrow D^{*-}p$	~ 3099	H1	—
$ddss\bar{u}: \Xi_{3/2}^{--}$	$\rightarrow \Xi^-\pi^-$	~ 1862	NA49	HERAB

Difference in results:

- decays are clear but production is unknown

CDF detector

At Fermilab:

Tevatron $p\bar{p}$ collider

General purpose detector:

vertexing

SVX

\vec{P} measurements

COT

particle ID

TOF, COT

muons

muon system

